Risk-Based Explosives Safety Criteria Overview

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Abstract

The Risk-Based Explosives Safety Criteria (RBESC) Working Group (Team) was chartered in the summer of 1997 to define the feasibility and plan of action for adopting risk-based criteria for explosives safety within the Department of Defense (DoD). The team was sponsored by the four services and the DoD Explosives Safety Board (DDESB). This paper provides an overview of the background, merits, and implementation plan for risk-based standards.

Risk-based safety criteria are gaining wider acceptance within the U.S. safety community. In 1997, a formal set of standards was adopted by the National Range Commanders Council. Other nations have used risk-based standards in a variety of safety applications. In the explosives safety area, Switzerland, Norway, Germany, the United Kingdom, and Australia have a long history of applying risk analysis to explosives safety. All of this previous experience, as well as numerous papers recommending a risk-based approach, provides a foundation for implementing risk-based standards.

Risk-based standards provide fuller and more specific information to the decision maker to assess the merits of siting, waiver requests, and allocation of safety resources. They can be used to supplement current use of quantity-distance.

A plan of action for implementation is under review by the Explosives Safety Board. The methodology developed will be presented in the Risk-Based Explosives Safety Criteria Session.

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Preface

The Risk-Based Explosives Safety Criteria Team was formed in August 1997 by the Chairman, DoD Explosives Safety Board (DDESB), to study the feasibility and desirability of risk-based explosives safety criteria.

Team Members include the following:

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DDESB	Mr. Charles Cates	DDESB Secretariat
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This is one of two papers presented at the 28th DoD Explosives Safety Seminar originating from this team. The other is entitled "Risk-Based Explosives Safety Methods."

1.0 INTRODUCTION

Since the 1930's, decisions in the U.S. regarding the siting of explosives have been made using Quantity-Distance (Q-D) criteria. That criteria considers the quantity of explosives and the relationship of the exposed site in order to determine the needed separation distance to other facilities or activities where persons might be exposed.

Numerous papers have suggested that improved methodologies exist to evaluate the risks associated with explosives. In fact, nations including Switzerland, Norway, Netherlands,

United Kingdom (UK), and Australia have implemented risk-based decision making with respect to explosives siting. This paper is the product of a 15-month study to develop a method of conducting risk-based assessments and to lay out a plan of action to implement the procedure within the U.S. Department of Defense.

The plan of action to implement this method includes developing a user-friendly model to evaluate waivers and exemptions using risk-based decision making.

2.0 BACKGROUND

Quantity-Distance has been in use as a tool to assist in making safety judgments for 70 years. For the last 30 of those years, it has been recognized that Q-D, which considers only the explosive quantity and class to determine a safe separation distance, could be improved upon by including other considerations such as the type of activity, number of people, building construction, and environment to assess the overall risk of the operation. This section briefly describes selected background work in other countries and key U.S. papers leading to the work of the RBESCT.

2.1 Switzerland

In the late 1960's, a number of problems in ammunition storage arose in Switzerland. The problems could not be solved reasonably and economically using the existing safety regulations, so the people responsible for explosives safety began looking for alternative safety assessment models. The quantitative risk analysis approach was introduced and applied to the urgent problems. Since then the Swiss have gradually developed and improved a quantitative risk analysis approach, regulations have been written, and an organization has been established.[1]

2.2 United Kingdom

"*A risk-based approach to safety requires more openness of the experts, it presents decision makers with choices and responsibility, it is available to public scrutiny. The goals of explosives safety will be unchanged, the ways of achieving those goals will be very different.*"

- Dr. John Connor, Chairman of the UK ESTC

The Ministry of Defense United Kingdom (MODUK) Explosives Storage and Transport Committee (ESTC) funded work to study the feasibility of quantitative risk assessment (QRA) for explosives storage in 1983. The method developed since that time provides an estimate of an upper bound to the annual risk of fatality of an individual from the handling

[1] Bienz, Andreas F., "Swiss Safety Concept, Regulations and Organization in the Field of Military Explosives Safety," paper presented at the 5th International Symposium on Explosives Technology, 12-14 October 1994, hosted by the National Institute for Explosives Technology (NIXT), Pretoria, RSA

and storing of explosives as the product of two components: the maximum expected frequency of initiation and the expected lethality consequence of the worst credible accident.[2] The ESTC method requires the user to define details of the potential explosion site (position coordinates, store size, shape and construction) store contents (net explosives quantity and weapon type) and other relevant information. The user must also specify population densities around the site for both workers and the general public. Outputs are calculated in terms of the risks to individuals at exposed sites from all potential explosion sites which pose a threat. The outputs are used to support Q-D regulations in accordance with ESTC Leaflet 22.

The Explosives Storage and Transport Committee currently uses the RISKWING model for their quantitative risk assessments.

2.3 Norway

The ammunition storage regulations used in Norway are similar to NATO recommendations. Risk assessment is used to complement the regulations for approval of some ammunition storage.

During the late 1970s, one third of the licenses that were issued had a concession included with them. Many of the waivers were issued because of minor infringements with the quantity-distance rules. In 1989, it was decided that the number of waivers needed to be reduced. This was accomplished by seeking approval to license storehouses on the basis of risk assessment, building new storages, and accepting reduced availability.[3]

The Norwegians use a quantitative risk assessment approach that is similar to the Swiss approach. The model used to estimate risk is a modification of the Swiss AMMORISK program.

2.4 Australia

General licensing practices for storage and handling of explosive ordnance within the Australian Defence Force are based on criteria commonly referred to as Quantity-Distance rules. The principles are similar to that defined by NATO Manual AASTP-1. Current Defence policy is that risk assessment may be used to support applications for public and departmental risk waivers, and to assist in the licensing of ordnance handling and storage operations. Risk assessment is not used as an alternative to Q-D rules.

Risk assessment methodology is similar to that applied by the MODUK ESTC with only a minor variation in the techniques used to assess risk. The Individual Risk (IR) and Societal

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[2] Connor, J., Hewkin, D.J, and Sexstone, P.A., "Risk Management of UK Ministry of Defence Explosives Storage Activities," Minutes of the 27th DoD Explosives Safety Seminar Proceedings, Las Vegas, Nevada, 20-22 August 1996.

[3] Øiom, Hans, "Storage of Ammunition - Quantitative Risk Assessment - Evaluation and Further Approach," Minutes of the 27th DoD Explosives Safety Seminar Proceedings, Las Vegas, Nevada, 20-22 August 1996.

Risk (SR) are key outcomes and are considered separately, but not in isolation. IR is that risk related to the personal safety of an individual. SR deals with the frequency of incidents and the likely number of fatalities following an incident.

Australia has two software models available for QRA: AUSRISK for site risk assessments, and Q-RISK for "quick-scan" risk appraisals.

2.5 United States

Within the United States, risk-based standards have been sparsely used in other areas of safety with mixed results. Affecting the overall impression of their use have been several highly publicized examples of gross optimism in the predictions. Accidents such as Three-Mile Island and the space shuttle disaster have served to reduce acceptability of use.

Currently, there is growing recognition of the benefits of risk predictions in the aerospace and chemical industries. Numerous papers and studies have recommended broader use of risk-based measures. Three specific studies are noted here because they have a direct link to this work: Pacific Northwest Study, the Risk and Lethality Commonality Team (RALCT) Study, and the 1996 Corps of Engineers Huntsville Division (COEHD) study.

2.51 Pacific Northwest Study

In August 1996 at the 27th DDESB Explosives Safety Seminar, Pacific Northwest National Laboratory in conjunction with Bienz, Kummer, and Partner Ltd. of Switzerland presented a risk-based approach as a complement to the Q-D approach.[4]

The risk analysis defined in the paper is currently used by the Swiss. The risk analysis consists of four steps: event analysis, effect analysis, exposure analysis, and risk calculation. Once the risks are calculated, a risk appraisal is performed to determine if they are acceptable. The calculated risks are compared to criteria (from Swiss Department of Defense policy) to determine acceptability.

Risk is calculated using the following equation: R=F*D, where R is risk, F is frequency, and D is damage. When a risk appraisal is performed, the calculated risk is compared with the approved risk limits (criteria) for direct personnel, indirect personnel, and third persons. The perceived collective risk is evaluated to see if corrective measures need to be taken to reduce the risk.

To account for catastrophic events, an aversion factor is multiplied by the actual risk to give a perceived risk. In the Swiss approach there is not a criterion for perceived risk but

[4] Wright, R.E., Hinton, M.F., Bienz, A.F., and Kummer, P.O., "Department of Defense Explosives Safety Criteria: Risk-Based Approach as a Complement to the Quantity-Distance Approach," Minutes of the 27th DoD Explosives Safety Seminar Proceedings, Las Vegas, Nevada, 20-22 August 1996. This approach was not implemented due to cost.

there is a "willingness-to-pay" approach. The "willingness-to-pay" sets an upper limit on what is reasonable to pay for risk mitigations to save a person's life (not on the value of the life).

Swiss DoD policy states that explosives safety workers should not incur a higher risk than the average working public. They use the computer model RISKAMEXS to perform explosives safety risk assessments.

2.52 RALCT

The Risk and Lethality Commonality Team (RALCT) was formed as a Range Safety Group (RSG) by the Range Commanders' Council (RCC) in February 1996.[5] The purpose of the RSG was to reach consensus on reasonable common standards for debris protection criteria and analytical methods. Before this group was formed each national range used its own set of criteria and analytical methods for calculating risks to personnel.

Risk-based criteria were developed to protect personnel from potentially lethal debris. Personnel protection criteria were defined for the general public and mission essential personnel (individual and collective risk).

Once the criteria were defined, five types of logic were used to justify the RCC criteria: consistency with other safety criteria, legal considerations, similar regulatory experience, comparable accident statistics, and correlation to other criteria.[6]

The RALCT defined many of the analytical and philosophical approaches used by the RBESCT.

2.53 COE - August 1994 (26th Seminar) This paper is one of a series of papers recommending use of system safety risk assessment principles.

In this paper, the Corps of Engineers Huntsville Division (COEHD) proposed using the Risk Assessment Code (RAC) matrix defined in MIL-STD-882C to determine inhabited building distance (IBD) separations.[7]

MIL-STD-882C establishes procedures for evaluating the risks associated with the operation of Army and DoD facilities. These procedures can be used to qualitatively evaluate the severity of an event as well as the probability of occurrence. The combination

[5] Standard 321-97, "Common Risk Criteria for National Test Ranges, Subtitle
published by Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, New Mexico 88002-5110.

[6] Pfitzer, Tom and Correa, Alice, "Debris Safety Standard for Launching from National Ranges," Proceedings of the 15th International System Safety Conference, Washington, DC, 13-17 August 1997.

[7] LaHoud, P.M., Douthat, C.D., and Zehrt, W.H., "A Risk Based Model for Determination of Inhabited Building Distance Siting Criteria," Minutes of the 26th DDESB Explosives Safety Seminar, Miami, Florida, 16-18 August 1994.

of the two in the form of a risk matrix provides decision makers with a tool to evaluate the relative risk associated with a particular explosive source.

The proposed risk model is based on two components: hazard severity and hazard probability. Total quantity of explosives and the scaled range are identified as hazard severity. Type of construction, function of facility, and expected occupancy level are used to determine a hazard probability. Using the RAC matrix, the risk to the public beyond IBD can be determined. There are two assumptions in this approach: that only risks from overpressure are considered, and that an event will occur.

2.7 The Benefits of a Risk-Based Approach

The intended uses of the risk-based approach include assessing waivers and exemptions as well as determining the approval level for violations of the standard. Currently, waivers or exemptions are authorized without quantified knowledge of the risks taken. The criteria is inflexible (require waivers for non-compliance). Perhaps most important, the use of Q-D does not provide consistent risk or damage criteria.

Numerous benefits have been associated with a risk-based approach. They include:

- Providing decision makers with the knowledge of the actual risk that is being accepted,
- A decrease in the number of waivers required,
- Prioritizing non-compliance (since a level of risk can be associated with each),
- Quantitative measures of risk can be compared to established criteria,
- Providing a means for identifying and prioritizing risk contributors as well as ways to mitigate these contributors, and
- Cost savings resulting from: better utilization of real estate, less expensive building designs, standardized waiver review and processing, and increased mission capability.

As a minimum, the benefits include consistency, a basis for decision making, reducing potential liability, and quantifying the risks that are taken.

In contrast, there are at least two factors which may reduce the benefits. More training may be needed because of the change to a new siting approach (compared to Q-D) and more data is needed to calculate risk.

3.0 RBESCT Process

The RBESC team, chartered to study the feasibility of risk-based explosives safety criteria, met every 4-6 weeks with specific goals for each meeting. Each goal was part of a four-part plan that included a case study, risk assessment methodology development, criteria development, and revisions to 6055.9-STD. All of the activities were managed using a PERT format to assure progress towards the goals (see Figure 1).

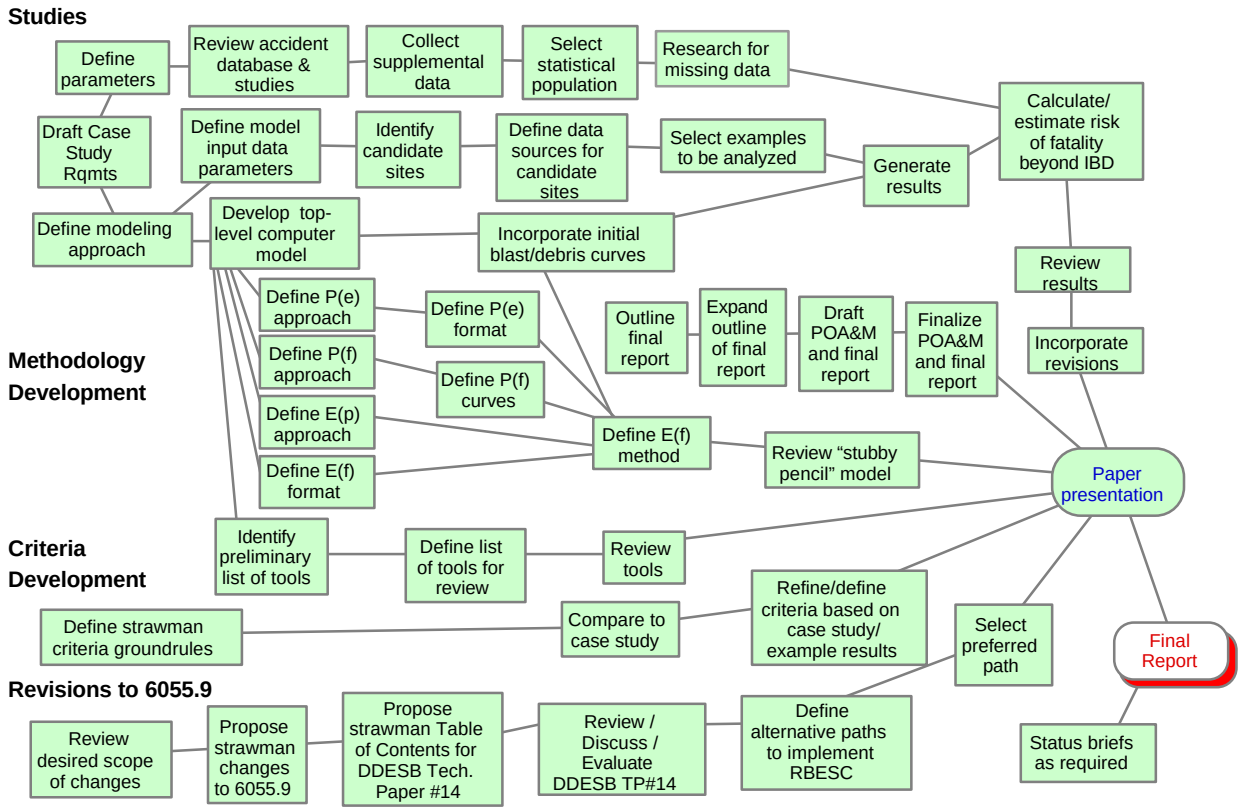

Figure 1: RBESCT Process

During FY98 the RBESCT used a goal-oriented management approach.

Case Study

Case studies were proposed to test the methodology selected and to determine what quantitative risks are allowed under the current standard (6055.9-STD). A case study requirements form was given to the service members of the team to obtain data for the case study. Each service member was asked to select several sites and to gather the information requested on the case study requirements form. Numerous problems associated with the initial data collected helped clarify the data needs and definition of terms.

To obtain initial results, hypothetical cases were used to demonstrate the risk-based methodology.

Risk Assessment Methodology Development

The goal was to define a set of repeatable steps for conducting quantitative risk assessments. To achieve this, the desired product of the assessment was selected. Expected fatalities from an unplanned explosives event was chosen as the basic measure. This measure was calculated as the product of three variables, probability of event, exposed personnel, and probability of fatality given an explosives event. Each of the three variables were studied and methods to calculate each were defined.

The product of this part was a step-by-step form for calculating expected fatalities.

Criteria Development

The selection of specific criteria is determined by policy. During the initial phase of the study various underlying policy and criteria options were defined for consideration. They will be finalized in the follow-on effort, Phase II.

Revisions to DoD 6055.9-STD

DoD 6055.9-STD documents the current use of Q-D criteria. The intent of the team was to supplement existing Q-D guidelines with a risk-based approach. It was determined that only minor changes to 6055.9-STD would be needed and a DDESB technical paper should be published to describe the use and methodology of risk-based decisions. An outline for the DDESB technical paper was drafted in Phase I. This outline will be used in Phase II to develop the DDESB technical paper.

4.0 Major Findings

Major Findings of the RBESCT:

- *Overall, Q-D risks are acceptable; however, Q-D risk at given K factors does not provide consistent risk numbers.*

It is no surprise that adding major considerations to an evaluation changes the results. The Q-D approach considers the quantity, class of explosives, the distance, and the desired protection level (K factor). The addition of other major factors such as the type of activity, the PES structure, and the ES structure result in significant variation in the risks. This augments, but in no way diminishes, the excellent protection which the Q-D approach has been providing.

- *The U.S. is far behind other countries which are using risk criteria.*

The literature and our colleagues from NATO offer a historical basis of successful use of risk-based assessments by other countries.

- *Adopting a risk-based method will be beneficial.*

Benefits significantly outweigh the costs.

- *All technical problems can be modeled, but fidelity is still a debate.*

Probabilistic formulas are used to determine risks. A fundamental principle of such an approach is that the fidelity of the answer is no better than the least precise of its parts. Because of the large inherent uncertainty in event probability the precision of the answer will never be better than one order of magnitude. Other factors in the E_f equation can be modeled with much higher fidelity. Therefore, the issue as to how much fidelity should be used will be addressed in the follow-on effort.

- *Multiple implementation approaches are available. The approach must be simplified.*

The debate over the best method, approach, and criteria can lead to "no decision" and preempt the potential for overall benefit. Therefore it is important to keep methodology simple, concise, and mathematically correct. Simplicity improves the understanding and leads to widespread use.

- *Consensus must be established in the use of risk numbers.*

When methods become standard, many benefits accrue. These include better understanding, less need for training, widespread acceptance, and stronger legal basis. Since there are many optional applications of risk numbers and many interested government agencies, there is a large potential for a bottoms-up development of their use resulting in non-conformity. The RBESC is in a position to lead in firmly establishing the proper use of the risk-based approach in explosives safety, and as a by-product, to provide broad and far-reaching benefits to other safety disciplines.

5.0 Plan of Action

The major goal of the risk-based explosives safety decision-making model is to evaluate the risk acceptability of site plans unable to meet Q-D criteria. To date, significant progress has been made toward that goal. Implementation of a risk-based explosives safety standard should involve testing and trial execution prior to full field-level implementation.

Completion of the risk-based model will require finalization of the P_e matrix, developing a complete set of $P_{f/e}$ curves, and adoption of risk-based criteria. When these steps are completed, DDESB Technical Paper 14 will be drafted along with a prototype of the RBESCT model. The model will be field-tested initially in a limited distribution (to be determined by each Service member to the RBESCT). Ultimately, the model will reside as a Web-based application accessible either through an Internet provider, or through a Remote Access Server (RAS) for those sites without an Internet capability.

In support of the Web-based model, training materials will be developed and disseminated. It may also be desirable to design the automated model to be compatible with other DoD site-planning software programs.

The progress to date and plan of action toward implementation are shown in Figure 2. Phase I of the study is now complete.

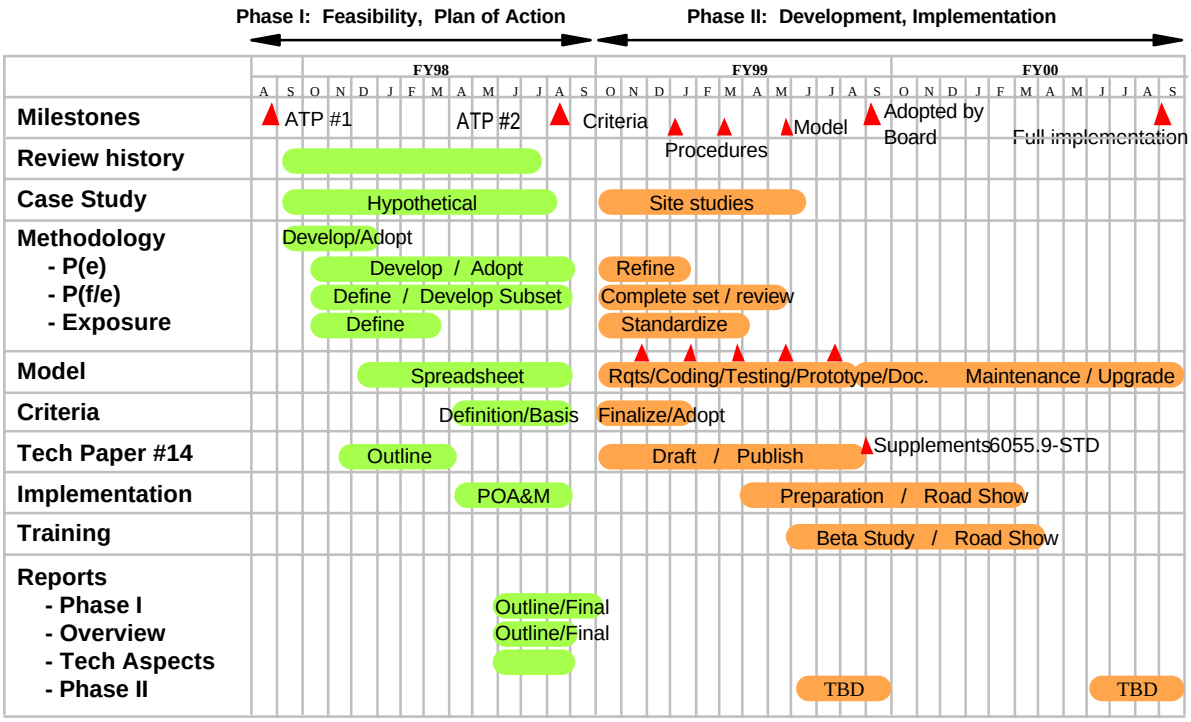

Figure 2: Plan of Action and Milestones

During Phase II the following activities are planned:

Case Studies. Several sites will be selected to apply the techniques developed in Phase I. This process is intended to identify any problem areas in the mechanics of conducting an assessment. Simplifications and improvements will result.

Methodology. The basic methodology has been adopted. Each of the three parts will be improved in Phase II.

P_e - Refinements on the P_e matrix will be included based on comments to the Phase I prototype.

$P_{f/e}$ - A subset of the desired $P_{f/e}$ possibilities was addressed in Phase I. This set will be expanded and reviewed by several independent analysis approaches.

Personnel Exposure - The method of calculating exposure has been defined to include numerous considerations. The methodology for handling these considerations will be standardized.

Model - Currently a prototype model exists in manual form. This model will ultimately be provided as software via the internet to multiple users. To achieve this goal a short but effective software development plan will be executed which includes the milestones commonly used in software development.

Criteria. The basis for the criteria has been defined. Selection of criteria is a policy level decision. To facilitate this selection, various policy options will be provided for review.

DDESB Technical Paper #14. An outline of the paper has been prepared. This paper will be drafted and published.

Implementation. A trial run will be conducted at the service headquarters and DDESB level. This study is intended to exercise the decision making process. Data from site studies will be used to feed the trial run.